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**Cognitive Engineering Models
in
Space Systems**

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Background

NASA space systems, including mission operations on the ground and in space, are complex, dynamic, predominantly automated systems in which the human operator is a supervisory controller. The human operator monitors and fine-tunes computer-based control systems and is responsible for ensuring safe and efficient system operation. In such systems, the potential consequences of human mistakes and errors may be very large, and low probability of such events is likely. Thus, system design cannot be based on direct empirical evidence from system operation and accidents, but has to be judged by predictive models of human-system interaction. Furthermore, automation tends to transfer human from psycho-motor tasks that can be formally described to higher level cognitive tasks of supervision, problem solving, and decision making for which conventional behavioralistic studies are inadequate. Thus, models of cognitive functions in complex systems are needed to describe human performance and form the theoretical basis of operator workstation design, including displays, controls, and decision support aids.

Currently, there several candidate modeling methodologies (Jones and Mitchell, 1987 and 1989). They include the Rasmussen abstraction/aggregation hierarchy and decision ladder (Rasmussen, 1989), the goal-means network (Woods and Hollnagel, 1987), the problem behavior graph (Newell and Simon, 1972), and the operator function model (Mitchell, 1987). These models are very similar in high-level goals and general flavor differing primarily in details that are linked to the specific domains in which they evolved and the application for which they were initially used. For example, the Rasmussen, Woods, and Hollnagel models were initially defined in the area of continuous process control such as nuclear power; whereas, Mitchell's model was developed for discrete systems such as satellite ground control and automated manufacturing system control. In addition, the former models initially were descriptive, attempting to characterize actual operator activities, particularly in situations involving human error. The operator function model represents normative operator behavior--expected operator activities given current system state.

Progress of the Research Program

The research conducted under the sponsorship of this grant focuses on the extension of the theoretical structure of the operator function model and its application to NASA Johnson mission operations and space station applications. The operator function model shows much promise as a 'macro' or engineering model of human performance that can complement 'micro' or cognitive science models.

The initial portion of this research consists of two parts. The first is a series of technical exchanges between NASA Johnson and Georgia Tech researchers. The purpose is to identify candidate applications for the current operator function model; prospects include mission operations and the Data Management System Testbed. The second portion will address extensions of the operator function model to tailor it to the specific needs of Johnson applications. For example, the inclusion of a model feature to represent initiation and execution of pre-defined procedures or checklists is a potential extension. The enhanced operator function model methodology will be used for both performance modeling and system design. Follow-on research will explore particular applications identified in this first phase.

At this point, we have accomplished two things. During a series of conversations with JSC researchers, we have defined the technical goal of the research supported by this grant to be

the structural definition of the operator function model and its companion computer implementation, OFMspert. Both the OFM and OFMspert have matured to the point that they require infrastructure to facilitate use by researchers not involved in the evolution of the tools. As a case study, we will work with JSC researchers to model a JSC application. The ease of use and/or difficulties will be observed and used as input for the more formal specification of an OFM/OFMspert structure.

The second accomplishment this year was the identification of the Payload Deployment and Retrieval System (PDRS) as a candidate system for the case study. Christine M. Mitchell, the principal investigator, and Dave Thurman, a graduate student in the Center for Human Machine Systems at the Georgia Institute of Technology, visited JSC in May and spent two days exploring various JSC applications. In conjunction with government and contractor personnel in the Human-Computer Interaction Lab, the PDRS was identified as the most accessible system for the demonstration.

Pursuit to this a PDRS simulation was obtained from the HCIL and an initial knowledge engineering effort was conducted to understand the operator's task in the PDRS application. The preliminary results of the knowledge engineering effort and an initial formulation of an operator function model (OFM) are contained in the appendice.

Since additional funding is not available for the continuation/extension of this project, this document serves as the final report. In addition to the modeling and knowledge requirements work summarized in appendices A and B, Appendix C contains a copy of a chapter written by the Principal Investigator, Cognitive Engineering Models: A Prerequisite to the Design of Human-Computer Interaction in Complex Dynamic Systems. The chapter will appear in P. Polson (ed.) *Human Computer Interface Design: Success Cases, Emerging Methods, and Real-World Context*. New York: Morgan Kaufman. This text grew out of a NASA Johnson-sponsored workshop. Mitchell's chapter summarizes a modeling methodology design to structure knowledge of operator decision making in control of complex systems; the presentation is designed to be particularly useful to HCI designers with interests in applications for human operators in complex systems.

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Appendix A

Knowledge Requirments for the PDRS Flight Controller

**Knowledge Requirements for the
Payload Deployment and Retrieval System (PDRS) Flight Controller
in the Johnson Space Center Space Shuttle Mission Control Room**

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Preface

This document describes the knowledge needed by the Payload Deployment and Retrieval System (PDRS) flight controller for monitoring and troubleshooting the PDRS system in the NASA Space Shuttle. The PDRS flight controller is housed in Johnson Space Center's Space Shuttle Mission Control Room. The flight controller's responsibilities are to monitor the PDRS for possible faults, to identify faults when they occur, and to take the appropriate corrective action in the event of a fault. The intent of this document is to define general knowledge requirements to support the development of an Operator Function Model (OFM) of these activities. This document is concerned with only the flight controller's task of monitoring the PDRS during the deployment, stowage, release, and latching activities. It is not concerned with the flight controller or shuttle crew's actions during payload deployment and retrieval activities.

This document contains three sections. The first section provides an overview of the PDRS as a component of the Space Shuttle. This information comes from the NASA PDRS manuals listed at the end of this document. Section Two describes the information available to the PDRS flight controller, both from Mission Control computer displays and from communication with shuttle crew. The final section describes the responsibilities of the PDRS flight controller. The information in the last two sections comes from the documentation accompanying the PDRS Flight Controller simulation software from Rice University (Cooke, 1992). Appendix A describes the PDRS displays and controls used by the astronauts in the shuttle. Appendix B describes the operational states of the PDRS during payload deployment and retrieval activities. Appendix C provides a glossary of acronyms used in this document.

Section 1: PDRS Overview

The PDRS has five operational stages: deployment, release, payload operations, latching, and stowage. Payload operations include activities such as deploying payload, grasping objects outside the shuttle, and inspecting the shuttle and its payload. While the payload operations are the primary purpose of the PDRS, this document will concentrate solely on the other four operational stages: deployment, release, latching and stowage. After the shuttle reaches orbit and prior to payload operations, the shuttle arm must be deployed from its stowed position and released from its support pedestals. It may then be used for payload operations. After the necessary payload operations are completed and prior to the shuttle payload doors being closed, the arm must be stowed for safekeeping. This consists of latching the arm to its supports and stowing the arm out of the way to enable the doors to be closed.

The PDRS flight controller must have general knowledge of the entire PDRS system, including its components, displays and controls, system limitations and operational modes. The rest of this section describes the five major components of the PDRS.

- Remote Manipulator System (RMS) - the shuttle telerobotic arm
- Manipulator Positioning Mechanisms (MPMs) - pedestals that support the arm while it is stowed
- Manipulator Retention Latches (MRLs) - latches which secure the arm to the MPM pedestals
- Closed Circuit Television System (CCTV) - an arm mounted TV camera and display system
- General Purpose Computers (GPCs) - computers which aid in operating the arm

The structural relationships between these components are shown in Figure 1. The dark portion shows the arm at rest on the supports and the lightened portion shows the arm in use for payload operations.

Remote Manipulator System (RMS) - The Remote Manipulator System, or “shuttle arm,” is a 50-foot long manipulator arm consisting of three structural elements connected via three joints in the arm. It works in a manner similar to the human arm. The arm is connected to the shuttle via the shoulder joint which connects the arm to the shoulder Manipulator Positioning Mechanism (see Figure 1). The elbow joint in the middle of the arm enables the arm to bend and is used in conjunction with the wrist joint to position the end of the arm. The end of the arm contains the payload capturing device, or end effector, used to grapple payload in the shuttle bay and deploy it. The end effector can also grapple free-flying payload, enabling it to be placed in the cargo bay. When not in use, the arm rests on three additional support pedestals (fore, mid, and aft MPMs) and is secured by latches (MRLs) on these three supports. The arm is always secured during launch, entry, and during any orbital maneuvers.

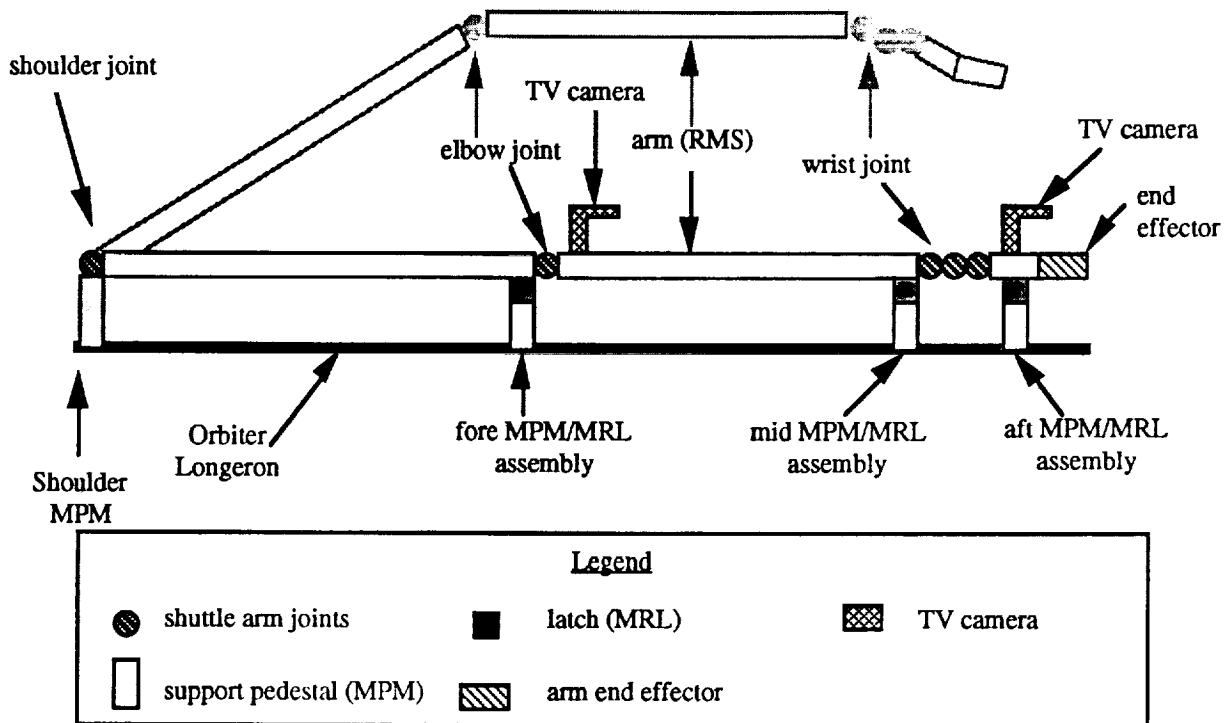


Figure 1 - Side view of PDRS components

Manipulator Positioning Mechanisms (MPMs) - The Manipulator Positioning Mechanism system serves three purposes in the operation of the RMS. First, the MPM pedestals support the arm at the base (shoulder joint) and three other positions (fore, mid, and aft) near the arm's joints when the arm is stowed (see Figure 1). Second, when deploying the arm, the MPM drive system rotates the support pedestals 31 degrees from their stowed position to the position from which the arm is deployed (see Figure 2). Finally, when the arm is stowed, it rotates the supports from their

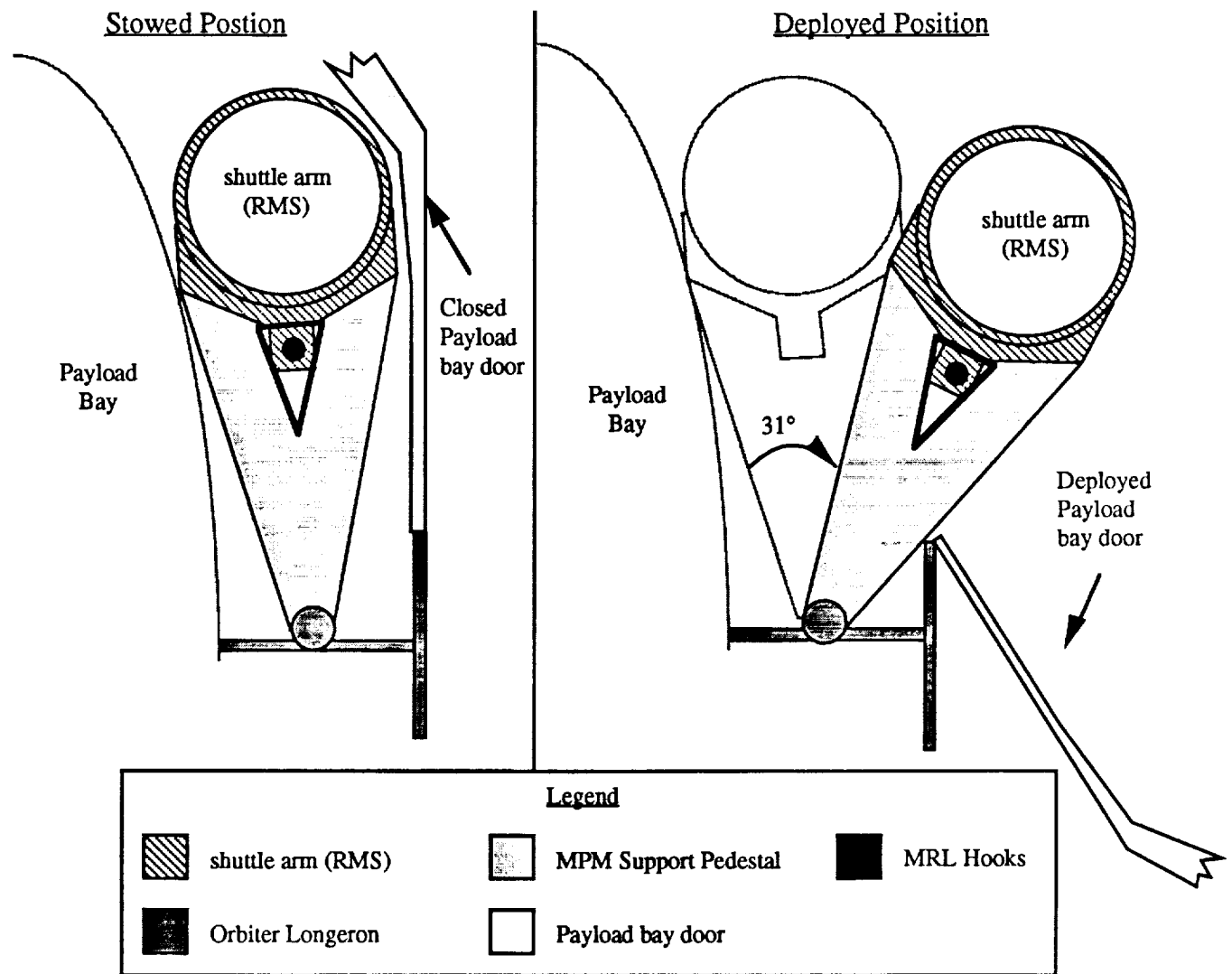


Figure 2 - Cross-section view of MPM Stowed and Deployed Positions. The MPM drive system consists of two redundant motors which rotate all four MPM support pedestals. The drive system also contains redundant microswitch sensors which sense the stowed or deployed state of the MPM support pedestals. The arm must be fully stowed in order to close the payload bay doors. The shoulder MPM pedestal contains equipment allowing the arm to be jettisoned from the shuttle in case of an emergency. The other three support locations (fore, mid, and aft) consist of a support pedestal and sensing equipment which indicates when the arm and support are in ready-to-latch, latched or

released conditions. On top of each of these support pedestals is a Manipulator Retention Latch, which is used to secure the arm to the support pedestal (see Figure 3).

Manipulator Retention Latches (MRLs) - The Manipulator Retention Latches, located on top of the MPM support pedestals, are used to secure the arm to the MPM pedestals. When the MPM microswitches indicate that the arm is in the ready-to-latch position (as shown on the left side of Figure 3), the operator issues the "LATCH" command and the MRL retention hooks secure the arm to the MPM support pedestals (shown on the right side of Figure 3). Dual redundant motors drive the latch system. All three MRL latch systems (fore, mid, and aft) are all controlled from a single switch and are engaged and disengaged simultaneously. The latches also contain redundant microswitches which indicate whether the arm is in a latched, released, or in-between state.

Closed Circuit Television System (CCTV) - The Closed Circuit Television System consists of a camera and viewing light mounted on the wrist section of the arm (see Figure 1) and camera displays located at the PDRS control center. An additional camera can also be mounted on the elbow joint with pan/tilt capabilities. This system is used primarily for payload handling operations and can be used for shuttle and payload inspections.

General Purpose Computers (GPCs) - The System Monitoring (SM) GPC is used to operate the PDRS in one of its computer-assisted modes for moving the arm. The System Monitoring GPC also provides status information on the PDRS on its computer displays. More information on the PDRS computer displays is given in Appendix A. A description of the PDRS computer-assisted and manual operational modes is given in Appendix B.

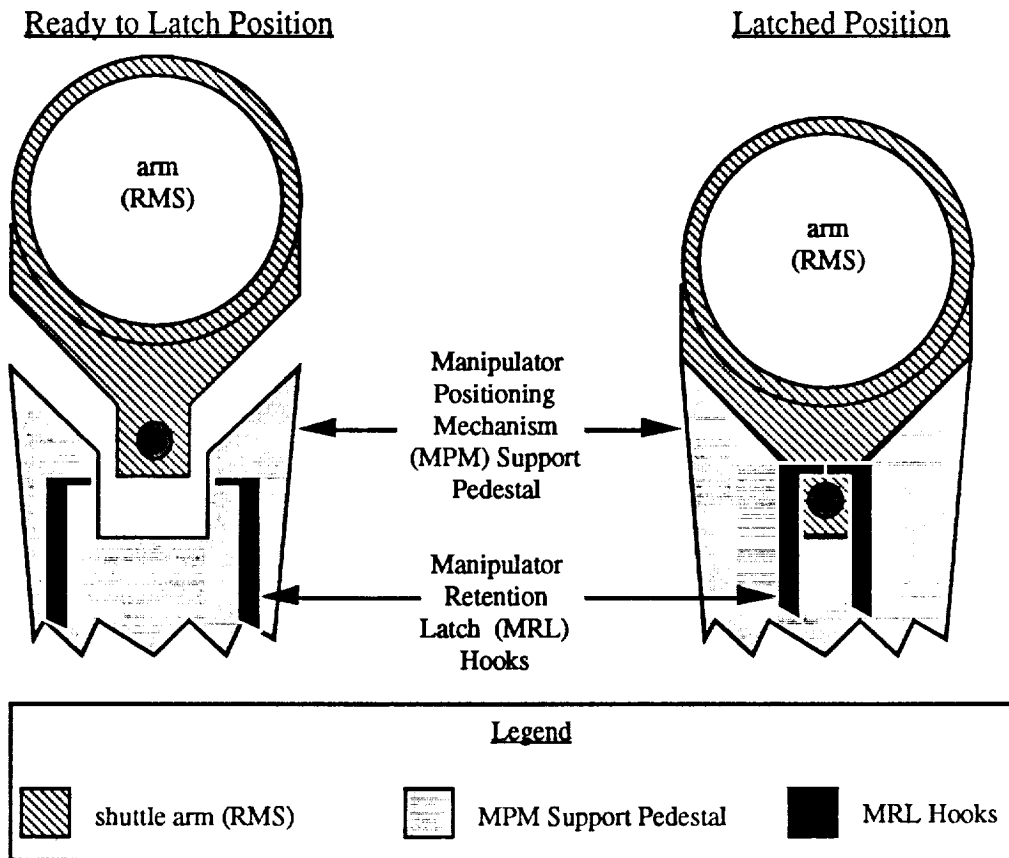


Figure 3 - Cross-section view of Manipulator Release Latch (MRL)

Section 2: PDRS Flight Controller Displays

The PDRS flight controller at Mission Control has a set of displays which indicate the status of the various components and microswitches described in Section 1. These displays are different from those on-board the shuttle, but should be in agreement with the shuttle displays. Rice University developed a Macintosh-based simulation of the PDRS flight controller activities (Cooke, 1992) to study the strengths and weaknesses of commonly used knowledge elicitation techniques. The simulation presents information similar to that used by the PDRS flight controller at Johnson Space Center and was used as the knowledge source for the following descriptions of the flight controller's displays.

The responsibility of the flight controller is to diagnose the state of the PDRS as either nominal activity or as a fault condition, to diagnose the cause of faults, and to correct fault conditions when they occur. To accomplish this task, the flight controller uses information from the four displays and voice loop described below.

Section 2.1: MPM/MRL Display

Figure 4 shows the flight controller's MPM/MRL display which indicates of the status of the MPM and MRL microswitches. Section A of the MPM/MRL display contains two indicators which display the operational states of the MPM support pedestals and MRLs (latches). The MPM support pedestals can be either stowed or deployed and the MRLs can be either latched or released. In Figure 4, the MPM support pedestals are stowed and the MRLs are latched. Section B of the display indicates whether or not the MPM system and each of the three MRLs are

operating properly. It displays “nominal” if the equipment is operating properly and “off-nominal” if the equipment is not working properly. In Figure 4, the MPM system and all the MRLs are operating nominally. Section C of the MPM/MRL display shows the signals generated by the MPM and MRL microswitches. The top two rows in this section of the display are the indicators for the three sets of redundant MRL microswitches (fore, mid, and aft) and the bottom two rows are the indicators for the four sets of redundant MPM microswitches (shoulder, fore, mid, and aft). In Figure 4, the display indicates that the microswitches are signalling that the MRLs are latched and the MPM support pedestals are stowed. Section D displays the current command being executed by the crew. Figure 4 shows that the crew has given the command to deploy the deploy. The indicators in sections A, B and C are also redundantly color-coded to indicate nominal conditions (green), warning conditions (yellow), and off-nominal conditions (red).

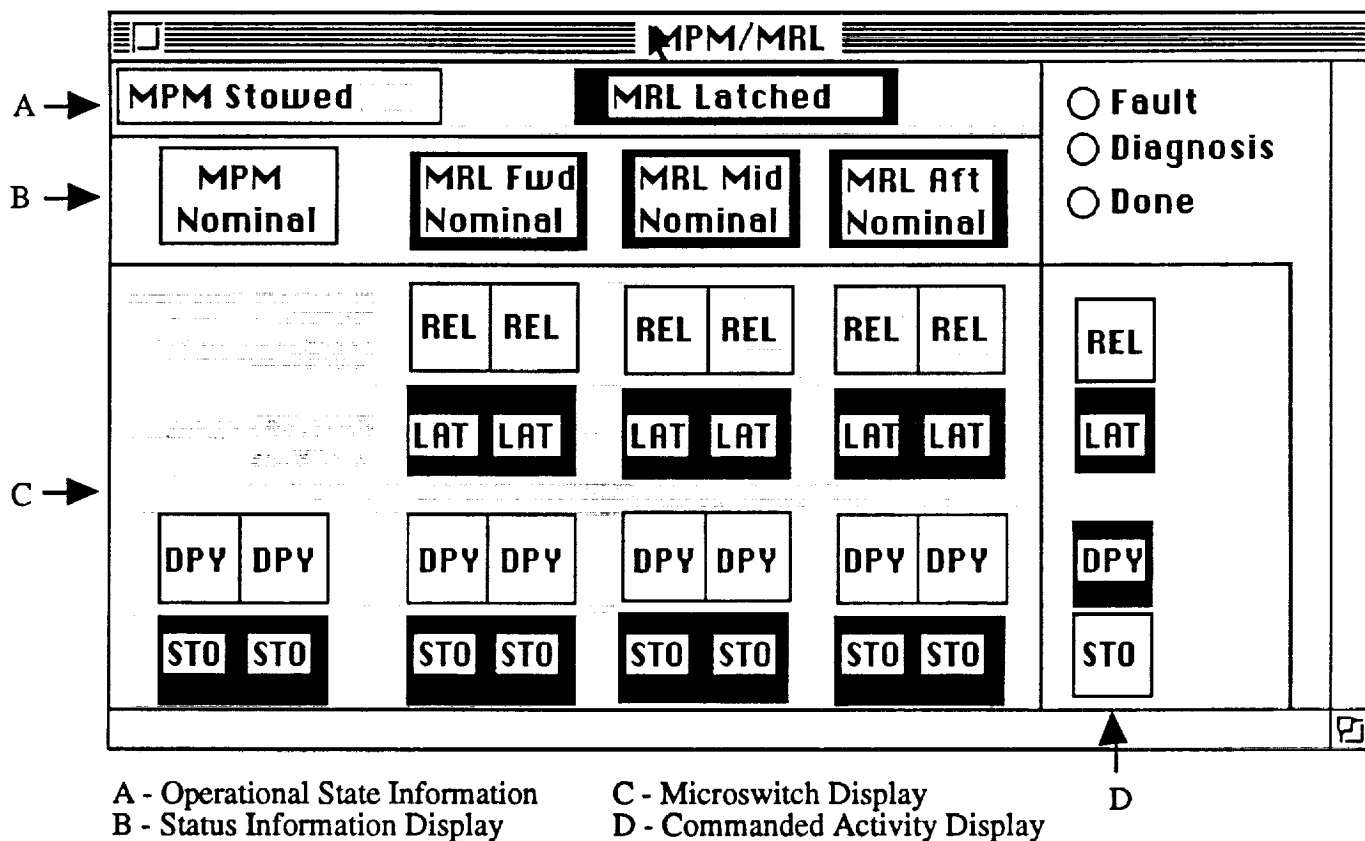


Figure 4 - Flight Controller MPM/MRL Display

Section 2.2: Op Stats Display

Figure 5 shows the Op Stats display as seen by the PDRS flight controller. The op stats information can be used to determine which of several kinds of faults may be occurring. There are 32 positions in the Op Stats display which contain either a "--" or "OP" signal. When all positions display the "--" signal, all systems are nominal. When "OP" signals are displayed, however, some kind of fault is indicated. The number of "OP" signals displayed indicates the type of fault present in the PDRS. The use of the Op Stats display to diagnose a fault condition is discussed in the Section 3.2.

MID MCA OP STATS				
OPER STAT	1	2	3	4
1	--	OP	--	--
2	--	--	--	--
3	--	--	--	--
4	--	--	--	--
5	--	--	--	--
6	--	--	--	--
7	--	--	--	--
8	--	--	--	OP

Figure 5 - Op Stats Display

Section 2.3: Talkback Operation Displays

The MPM/MRL display shows the flight controller what it believes is the state of the shuttle's MPM/MRL microswitches at all times. Due to equipment malfunctions, however, it is possible for the shuttle's talkback (indicator light) displays (see Section A.1) to disagree with the MPM/MRL display. To determine the state of the shuttle's talkback displays in the PDRS simulation, the flight controller uses the STO Talkback and LAT Talkback displays shown in Figure 6. The double-lined boxes in Figure 6 indicate that the STO Talkback is showing the MPMs are in the stowed position and the LAT Talkback is showing the MRLs are in the latched position. In this example, the shuttle's displays are in agreement with the MPM/MRL display in Figure 4.

Need to find out if the PDRS flight controller really has these, or if these were invented by the Rice folks.

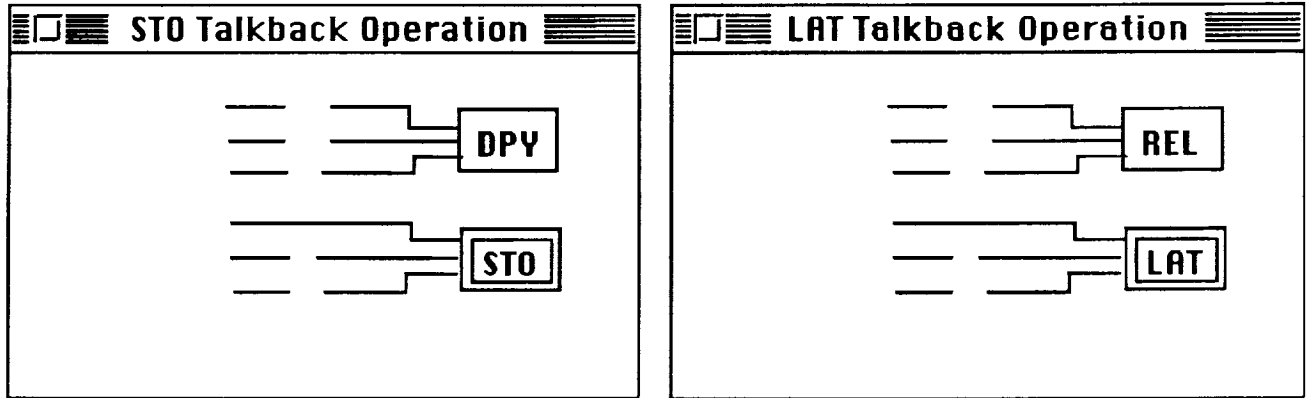


Figure 6 - Talkback Displays

Section 2.4: Voice Loop

The PDRS flight controller maintains communications with the shuttle crew via the mission control-to-shuttle voice loop. In the PDRS flight controller simulation, this voice loop is simulated with a text window showing the comments made by the shuttle crew as they operate the PDRS. Via this voice loop, the flight controller can also obtain additional status information from the shuttle crew, including crew actions and the status of shuttle PDRS displays.

Section 3: Functions of the PDRS Flight Controller

The PDRS flight controller must not only be familiar with the components of the PDRS but also understand the procedures for their proper use, troubleshooting, and repair. The flight controller's activities can be broadly defined in three categories: fault detection, fault identification and diagnosis, and fault correction. Fault detection consists of verifying that the states of the PDRS components, primarily the MPM and MRL microswitches, correspond to the current intended PDRS activity. When the flight controller has identified a component that is in an improper state for the current PDRS activity, a fault has been detected. Fault identification and diagnosis consists of identifying the actual fault that has been detected and diagnosing its cause. Fault correction consists of taking the appropriate corrective action to mitigate the identified fault.

Section 3.1: Fault Detection Activities

During PDRS operations, the flight controller monitors the status of the MPMs and MRLs to determine if the RMS has been properly stowed, released, deployed, or latched as required by PDRS activities. For example, if the PDRS is commanded to latch the arm to the MPM support pedestals, the flight controller monitors the MPM/MRL Display (Figure 4) to determine if the MRLs properly latch the arm to the support pedestals. The flight controller is also responsible for determining when improper commands are given, such as a latch command when the RMS is not in the ready-for-latch position. If all microswitch indicators on the MPM/MRL display are green and in agreement with the current commanded action (stow, deploy, release, or latch), the PDRS is being nominally operated. Any yellow or red microswitch indicators, disagreement between

microswitch states and the commanded activity, or disagreement between microswitches in a component indicates a fault.

Section 3.2: Fault Identification and Diagnosis Activities

When a fault condition is detected, the operator must determine the actual fault that has occurred in order to take the appropriate corrective action. In addition to the MPM/MRL display used to detect the fault condition, the operator uses the LAT Talkback Display and STO Talkback Display to identify the fault condition. Table 1 shows the 18 possible states of the PDRS as defined by the Rice University PDRS simulation. The first 14 states are fault conditions, while the final four states indicate the nominal operation of the PDRS. Columns 1, 3, 4, and 5 contain information from the MPM/MRL display (see Figure 4 and Section 2.1 above) and column 2 contains information from the LAT and STO Talkback displays (see Figure 6 and Section 2.3 above). The first three columns contain the state of the MRL (top) and MPM (bottom) microswitches. When only one word, e.g. "Latched", appears on a line it indicates that all microswitches are in agreement. When two words, e.g. "Rel/Lat", appears on a line it indicates that the microswitches are indicating the some MRLs are latched and some are released. The bolded text indicates the most recent state change in the MPM/MRL display. For example, if the word "Stowed" is in bold, the most recent state change has been from the MPM pedestals being deployed to their being stowed. The last column indicates the actual fault identified by the values in columns 1 through 5.

Table 1 - Fault Identification Rules

MPM/MRL MicroSwitch	LAT/STO Talkbacks	Commanded Activity	Overall Status	Color Coding	Identified Fault
------------------------	----------------------	-----------------------	-------------------	-----------------	---------------------

Latched Stowed	Latched Stowed	Latch Deploy	MPM Off Nominal	Yellow	Uncommanded Stow
Latched Deployed	Latched Deployed	Latch Stow	MPM Off Nominal	Yellow	Uncommanded Deploy
Latched Deployed	Latched Deployed	Release Deploy	MRL Off Nominal	Yellow	Uncommanded Latch
Released Deployed	Released Deployed	Latch Deploy	MRL Off Nominal	Yellow	Uncommanded Release
Latched Deployed	Latched Deployed	Latch Stow	MPM Off Nominal	Red	Failed Stow
Latched Stowed	Latched Stowed	Latch Deploy	MPM Off Nominal	Red	Failed Deploy
Released Deployed	Released Deployed	Latch Deploy	MRL Off Nominal	Red	Failed Latch
Latched Deployed	Latched Deployed	Release Deploy	MRL Off Nominal	Red	Failed Release
Latched Deployed	Latched Stowed	Latch Deploy	MPM Nominal	Green	MicroSwitch Talkback Incongruity
Latched Stowed	Latched Deployed	Latch Stow	MPM Nominal	Green	MicroSwitch Talkback Incongruity
Released Deployed	Released Deployed	Release Deploy	MRL Nominal	Yellow	Single Motor Release
Latched Deployed	Latched Deployed	Latch Deploy	MRL Nominal	Yellow	Single Motor Latch
Rel/Lat Deployed	Released Deployed	Release Deploy	MRL Nominal and Off-Nominal	Some Red Some Green	Partial Release
Rel/Lat Deployed	Latched Deployed	Latch Deploy	Nominal and Off-Nominal	Some Red Some Green	Partial Latch
Latched Stowed	Latched Stowed	Latch Stow	MPM Nominal	Green	Nominal Stow
Latched Deployed	Latched Deployed	Latch Deploy	MPM Nominal	Green	Nominal Deploy

Released Deployed	Released Deployed	Release Deploy	MRL Nominal	Green	Nominal Release
Latched Deployed	Latched Deployed	Latch Deploy	MRL Nominal	Green	Nominal Latch

Once one of the 14 faults has been identified, its cause must be diagnosed using the rules shown in Table 2. The identified fault condition from Table 1 plus the results of the Op Stats Display (see Figure 5 and Section 2.2 above) are used to diagnosis the cause of the fault. This diagnosis is then used to determine what corrective action should be taken by the shuttle crew and the flight controller.

Table 2 - Fault Diagnosis Rules

Fault Condition	Op Stats Display (# OPs)	Fault Diagnosis
Uncommanded Deploy Uncommanded Stow	2	MCA Relay Failure
Uncommanded Deploy Uncommanded Stow	0	MicroSwitch Failure
Uncommanded Latch Uncommanded Release	3	Dual Pole Failure
Uncommanded Latch Uncommanded Release	6	Single Pole Failure
Failed Stow Failed Deploy	2	Motor 1 Failure
Failed Stow Failed Deploy	1	MicroSwitch Failure
Failed Latch Failed Release	6	Motor 1 Failure
Failed Latch Failed Release	3	MicroSwitch Failure
Micro Switch / Talkback Incongruity	0	Talkback Failure

Single Motor Release Single Motor Failure	6	Motor 2 Failure
Single Motor Release Single Motor Failure	5	MCA Relay Failure
Single Motor Release Single Motor Failure	3	MicroSwitch Failure
Partial Release Partial Latch	6	Motor 1 Failure
Partial Release Partial Latch	3	MicroSwitch Failure

Section 3.3: Fault Correction Activities

Once the fault has been diagnosed, the flight controller is responsible for taking the appropriate corrective action. This may be as simple as reporting the failure to the shuttle crew or other personnel or as complicated as requiring the crew to perform in-flight maintenance (IFM) on some component of the PDRS. In the most extreme case, it can include jettisoning the shuttle arm. Table 3 provides the rules used by the flight controller to determine what corrective action to take given the fault condition. If the fault is a microswitch failure or dual pole failure, the flight controller checks the crew timeline to see if one of the crew members has enough time to perform In-Flight Maintenance (IFM). The crew timeline indicates when the members of the crew are scheduled for various activities. Sleep time and free time are also scheduled. IFM can only be requested if one of the crew has two-and-a-half continuous hours of sleep or free time available.

Table 3 - Corrective Action Rules

Fault Diagnosis	Corrective Action
-----------------	-------------------

MCA Relay Failure One Pole Failure	Turn AC motor circuit breaker OFF
MicroSwitch Failure Dual Pole Failure	Request IFM if appropriate, otherwise report Failure to Communications and Engineering
Motor 1 Failure Motor 2 Failure	Report Failure to Flight Director and Engineering If (fault = Failed Stow) then jettison arm at shoulder MPM
Talkback Failure	Report talkback failure to shuttle crew and Engineering

Section 4 - Operator Function Model (OFM)

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Cooke, N. M. Personal communication and informal notes. 1992.

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PDRS Malfunction Workbook (PDRS MAL 2102). Lyndon B. Johnson Space Center, Houston, Texas. April, 1988.

Appendix A - PDRS Displays and Controls in the Space Shuttle

The PDRS shuttle display and control system consists of two control panels and two computer displays located in the aft compartment of the shuttle. The control panels, labeled A8L and A8U in NASA documentation, are control and indicator panels located near the PDRS hand controllers. The computer display screens are part of the System Monitoring computer system and are located adjacent to the control panels.

Section A.1 - Control Panel A8L

Panel A8L contains the switches and talkbacks, or indicator lights, associated with the MPM and MRL systems. In the shuttle, panel A8L is configured to support two shuttle arms (port and starboard) although current shuttles are all configured with only a single (port) arm. The portion of panel A8L dealing with the MPM and MRL systems of the port arm (RMS) is reproduced in Figure 7. The control switches and talkbacks (indicator lights) in Figure 7 are described below.

RMS Stow/Deploy Talkback (DS4) - The RMS Stow/Deploy Talkback indicates the current deploy/stow status of the MPM support pedestals. It displays text or barberpole shading to indicate one of three possible systems states as follows.

- STO indicates the MPMs are in the stowed position (rotated in)
- DEP indicates the MPMs are in the deployed position (rotated out)
- Barberpole shading indicates the MPMs are between the stowed and deployed positions

RMS Stow/Deploy Switch (S5) - The RMS Stow/Deploy Switch commands the MPM support pedestals to rotate into either the deployed or stowed position.

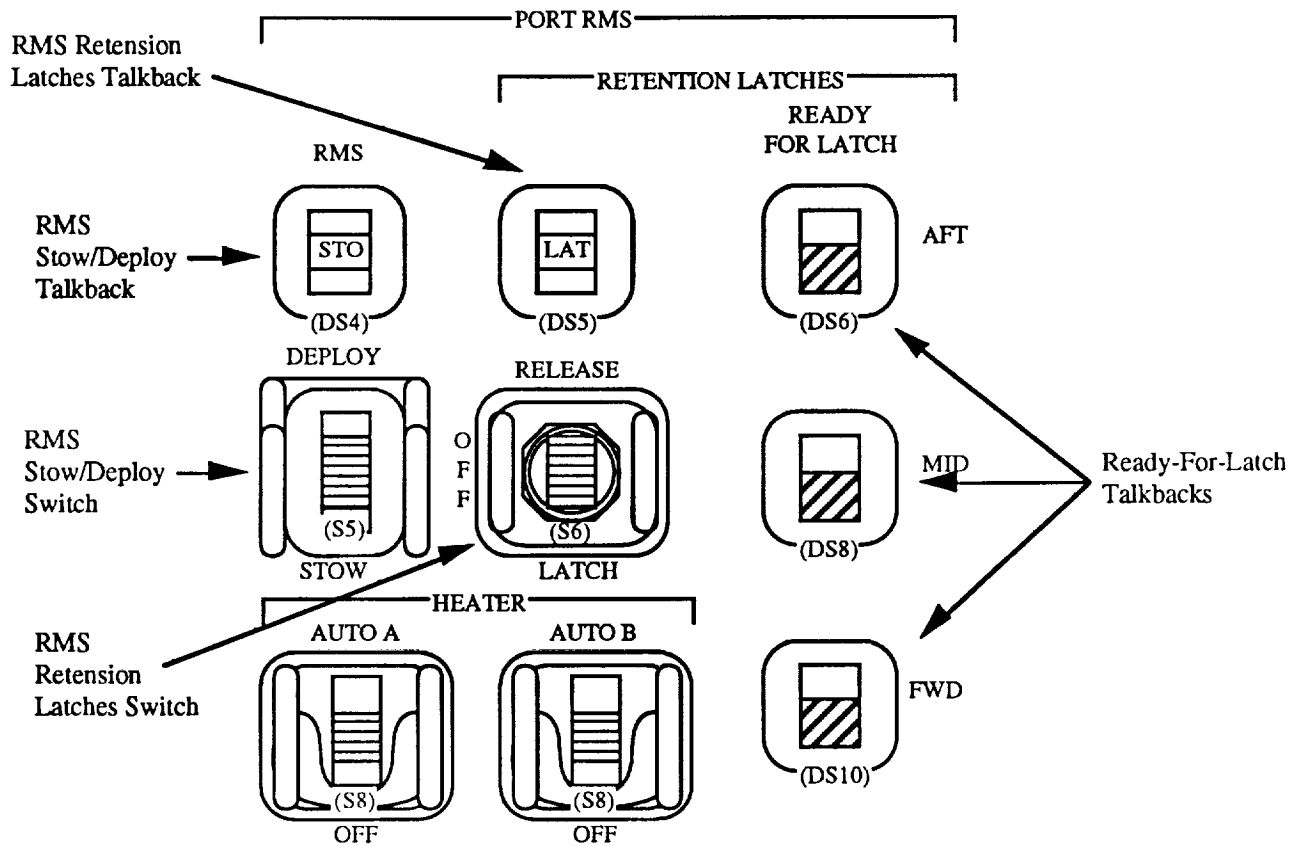


Figure 7 - Port RMS portion of Shuttle Control Panel A8L

RMS Retention Latches Switch (S6) - The RMS Retention Latches Switch is used to command the MRL system to latch or release the arm from the MPM supports.

RMS Retention Latches Talkback (DS5) - The RMS Retention Latches Talkback indicates the current release or latch status of all three latches (MRLs). It displays text or barberpole shading to indicate one of three possible systems states as follows.

- LAT indicates the MRLs are latched

- REL indicates the MRLs are released
- Barberpole shading indicates the MPMs are between latched and released positions.

RMS Ready For Latch Talkbacks (DS6, DS8, DS10) - The RMS Ready-For-Latch Talkbacks indicate whether or not the shuttle arm is in position for the MRLs to latch the arm to the MPMs. This is indicated by the talkbacks as follows:

- Gray shading indicates the arm is in position to be latched
- Barberpole shading indicates the arm is not in a position to be latched.

There are three talkbacks, one for each of the MPM/MRL combinations (fore, mid, aft).

Section A.2 - Control Panel A8U

May want to describe Panel A8U. Not really related to this task, but a description would provide more background information on the general use of the arm. Need to search through the NASA documentation to find out what is the purpose of this display.

Section A.3 - PDRS Control Display

The PDRS CONTROL is one of the displays in the System Monitoring computer related to the operation of the PDRS. It indicates the status of the shoulder MPM, the status of the retention latches, and if the arm is in the ready-for-latch position. It has two sections which present this status information: The RMS Shoulder Stow/Deploy Display section and the RMS

Latch/Release/Ready Display section. These sections of the display are shown in Figure 8 and described below.

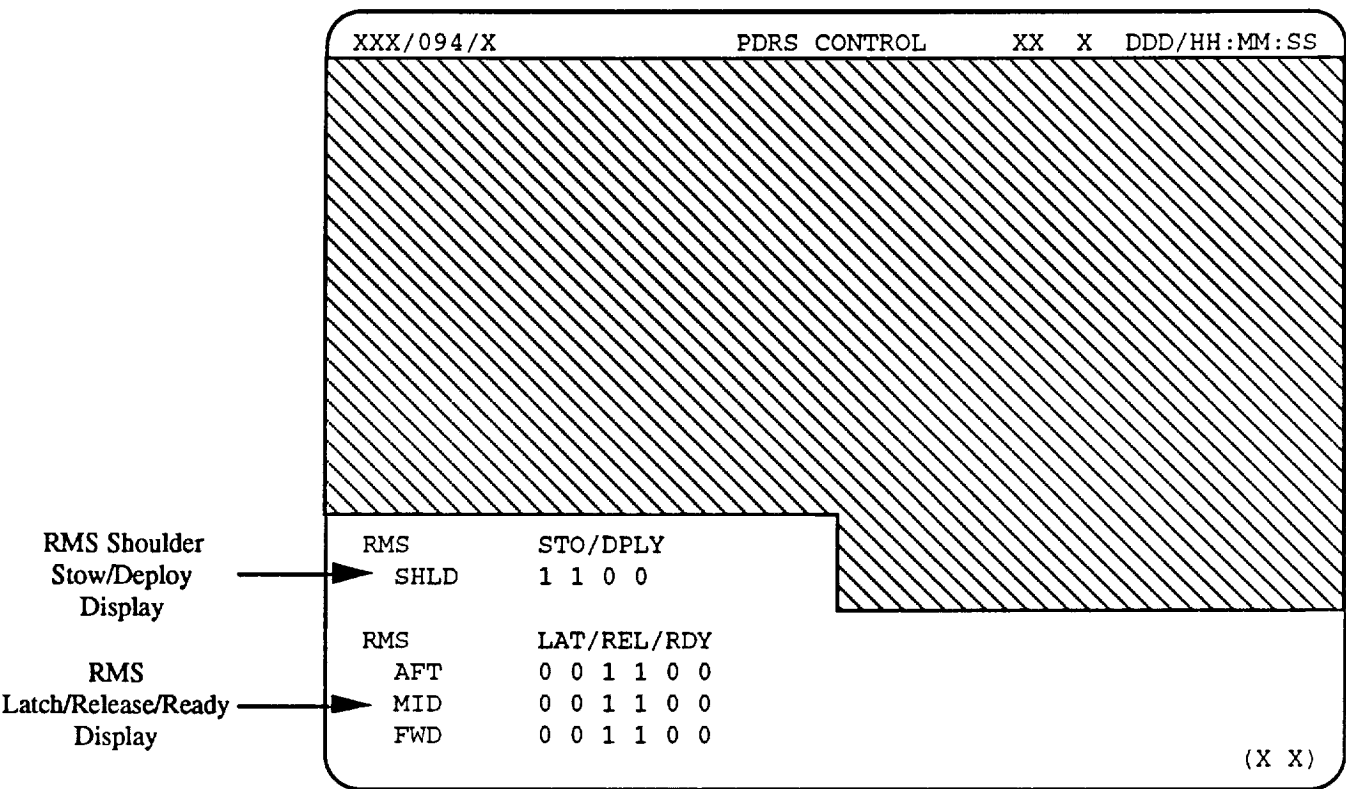


Figure 8 - PDRS Control Display

RMS Shoulder Stow/Deploy Display - Four microswitches on the shoulder MPM support pedestal indicate the stowed/deployed status of the pedestal. Two redundant microswitches indicate if the pedestal is deployed and the other two redundant microswitches indicate if the pedestal is stowed. The output of these four microswitches is displayed on the RMS Shoulder Stow/Deploy Display as shown in Figure 7. A '1' is displayed for each microswitch that is activated and a '0' is displayed for each that is not. The stowed microswitch indications are

displayed first and then the deployed microswitch indications. For example, Figure 8 indicates the nominal stowed status of the shoulder support pedestal.

RMS Latch/Release/Ready Display - Each of the three MRLs has a set of doubly redundant microswitches which indicate if the latches are in a latched or released position and if the arm is in a ready-for-latch position. The RMS Latch/Release/Ready Display shows the status of each of these microswitches for each of the three MRLs (aft, mid, forward) . A '1' is displayed for each microswitch that is activated and a '0' is displayed for each that is not. The latched microswitch indications are displayed first, followed by the released microswitch indications, followed by the ready-for-latch microswitch indications. For example, Figure 8 shows the indication that all MRLs are released and that the arm is not in a ready-for-latch position.

Section A.4 - PDRS Status Display

Need to describe this display, even though it isn't used in MPM/MRL tasks. Again, it would provide more background on the use of the arm.

Appendix B - PDRS Operational Modes

After being deployed and released, the shuttle arm can be used to maneuver payload from the payload bay into space or to grapple payload in space. It can also be used to visually inspect payload or the shuttle using the wrist-mounted TV camera. The PDRS astronaut must maneuver the arm to accomplish any of these activities. Movement of the arm may be accomplished using one of the following arm control modes.

Section B.1 - Automatic Control Modes

There are two automatic control modes available to the operator, preprogrammed and operator commanded.

Preprogrammed Automatic Control Mode - The preprogrammed automatic control mode has the capability for storing automatic sequences in the System Monitoring computer. Using the computer, four such sequences can be assigned for selection on Panel A8U. Each automatic sequence consists of a series of arm positions and attitudes. As many as 200 total positions and attitudes may be specified for up to 20 automatic sequences.

Operator Commanded Auto Sequences (OCAS) - The operator-commanded auto sequence moves the arm from its present position and attitude to a new position and attitude specified by the operator. After entering the desired position and attitude, the operator commands the computer to verify that the requested position and attitude are legal with respect to possible arm configuration

and capabilities. It is important for the operator to understand that the automatic modes do not check for collision avoidance and that careful observation of the arm is required at all times.

The automatic control modes are typically used for maneuvering a payload outside the payload bay or for maneuvering the unloaded arm to the pre-stowage position.

Section B.2 - Manual Augmented Control Modes

The manual augmented control modes allow the operator to direct the arm using two hand controllers. The PDRS computer processes the hand controller signals into a rate command for each joint of the arm. Five manual augmented control modes are available. For more information on these modes see pages 2-25 through 2-30 of the *PDRS Overview Workbook*.

Orbiter Unloaded Mode - When the arm is unloaded, the Orbiter unloaded mode may be used to control the position and attitude of the arm's end effector (grappling device). One hand controller specifies left/right, up/down, and front/back positioning of the end effector, while the other specifies yaw, pitch, and roll of the end effector. In the Orbiter unloaded mode, the motion of the arm is parallel to the shuttle's body coordinate system.

End Effector Mode - The end effector mode is similar to the Orbiter unloaded mode, except that the hand controller signals are translated about the coordinate system defined by the wrist-mounted TV camera. Front/back movement causes the wrist to move forwards/backwards along the

longitudinal axis of the camera. Similar translations are applied to left/right and up/down motions of the hand controller.

Payload Mode - The manual augmented payload mode is used when the arm is grasping payload to enable the operator to translate and rotate the payload in directions that correspond to the orientation of the payload.

Orbiter Loaded Mode - The Orbiter loaded mode is used to move the payload in relation to the shuttle. It is similar to the Payload mode, except that the translations from the hand controller signals to the arm movements are different. It is typically used for useful for berthing and unberthing operations.

Rate Hold Mode - While using any of the above manual control modes, the operator may press a button on one of the hand controllers which places the system in rate hold mode. In this mode, the current rate command is maintained when the operator releases the hand controllers. Once this rate has been established, additional rate bias can be superimposed by the hand controllers.

Section B.3 - Single-Joint Drive Control Mode

The single-joint drive mode allows the operator to selectively move the arm by controlling one joint at a time. The operator selects the joint to drive and then uses a toggle switch on panel A8U to supply a fixed joint drive signal. The computer interprets this signal and supplies commands to drive the selected joint. This mode is typically used for stowing and deploying the arm.

Section B.4 - Direct Drive and Backup Drive Control Modes

The direct drive mode is a contingency mode that bypasses all computer augmentation and allows the operator to directly drive the joints of the arm. The direct drive mode is typically used only when there is a problem with the computer system and one of the automatic or augmented control modes is not available.

The backup drive mode is a contingency mode that is used only with none of the other modes of operation are available. It can be used to maneuver a payload to a safe release position or to stow an unloaded arm.

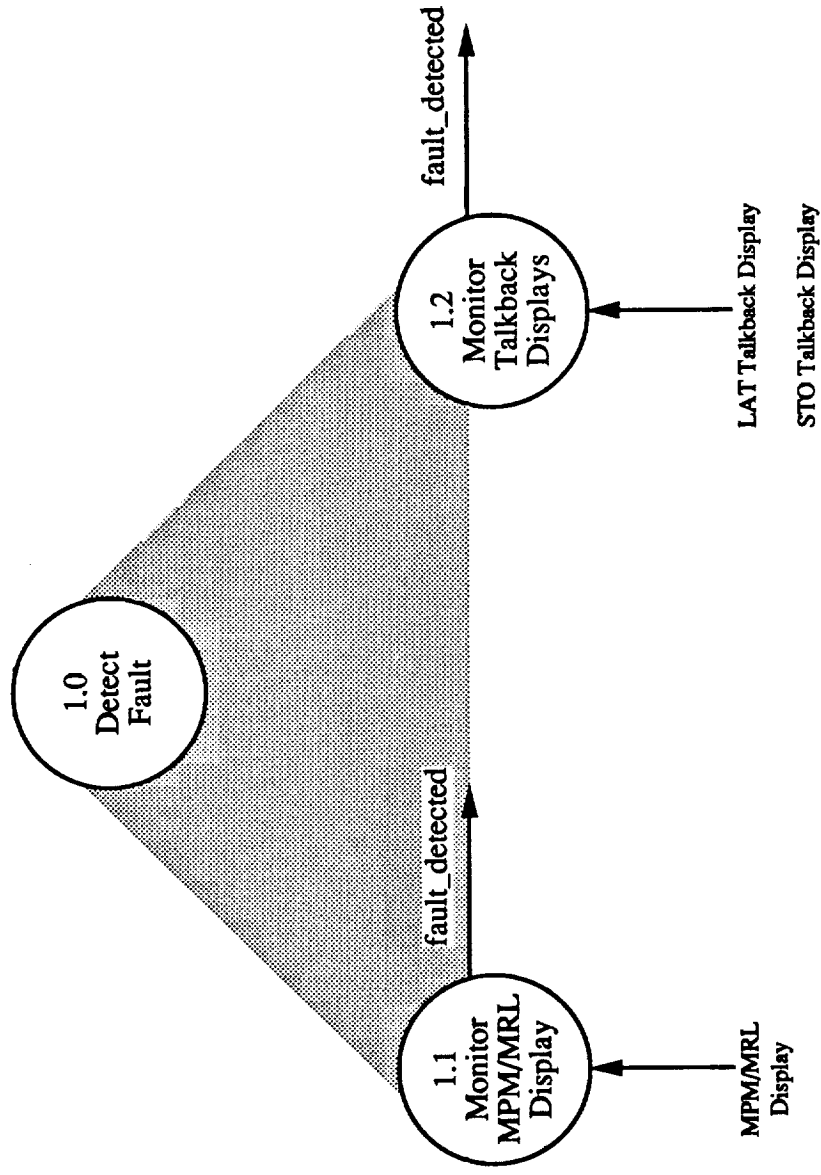
Appendix C - Glossary of Acronyms

CCTV	Closed Circuit Television - the television system consisting of two cameras mounted on the shuttle's arm and two displays located in the shuttle at the PDRS control station.
DEP	Deploy - used in PDRS displays to indicate when the MPM microswitches indicate that the MPM pedestals have been rotated out to the deploy position.
GPC	General Purpose Computer
IFM	In Flight Maintenance - servicing of equipment by shuttle astronauts during flight
LAT	Latch - used in PDRS displays to indicate when the MRL microswitches indicate the arm is latched to the MPM support pedestals
MPM	Manipulator Positioning Mechanism - the pedestal which supports the shuttle arm when it is not in use and is used to rotate the arm between its stowage and deployment positions.
MRL	Manipulator Release Latch - the latch which secures the arm to the MPM pedestal when the arm is stowed or in the process of being stowed or deployed.
OCAS	Operator Commanded Auto Sequence - a preprogrammed series of arm maneuvers used stored in the System Monitoring GPC allowing the computer to maneuver the arm automatically to perform a prescribed task.
Op Stats	Operational Stats - one of the displays used by the PDRS flight controller to determine the cause of a particular fault condition
OFM	Operator Function Model

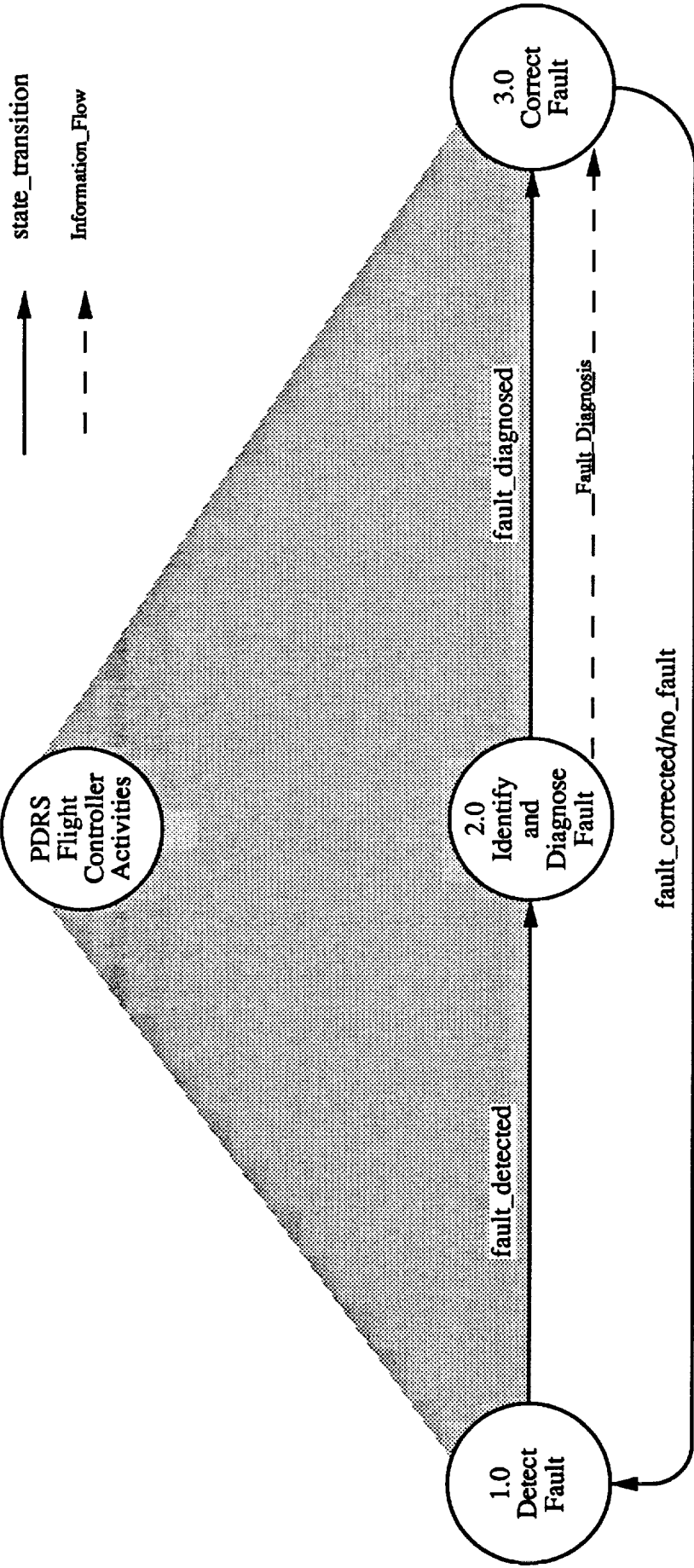
PDRS	Payload Deployment and Retrieval System - the shuttle system consisting of the arm and all its components, the MPM and MRL systems, the CCTV system, and the associated computers, controls and displays.
REL	Release - used in PDRS displays to indicate when the MRL microswitches indicate the arm has been released from the MPM support pedestals
RMS	Remote Manipulator System - the shuttle's telerobotic arm
RMO	Remote Manipulation Operations - use of the arm for payload deployment and retrieval activities
SM	System Monitoring (GPC) - one of the General Purpose Computers on board the shuttle that is used for monitoring and operating the shuttle arm.
STO	Stow - used in PDRS displays to indicate when the MPM microswitches indicate that the MPM pedestals have been rotated in to the stow position.

Appendix B

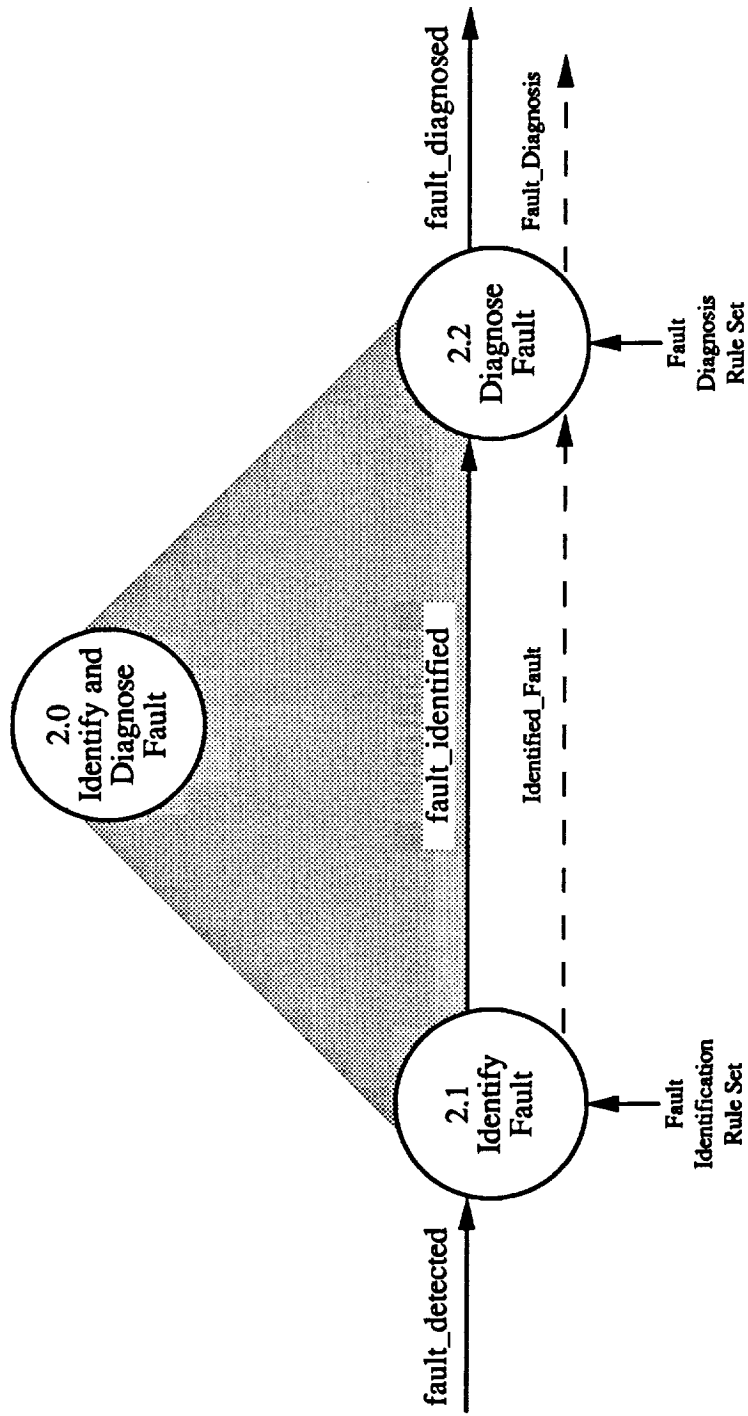
Preliminary PDRS Operator Function Model (OFM)



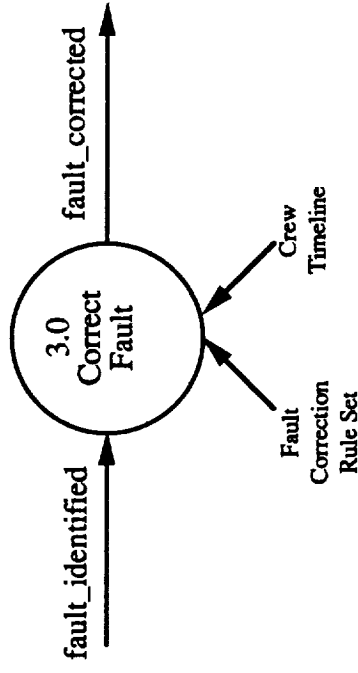
Payload Deployment and Retrieval System
Operator Function Model
Level: **1.0**

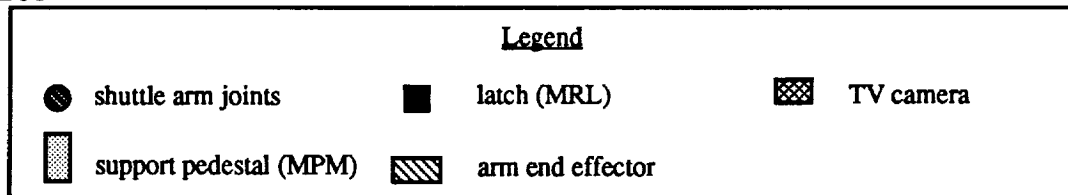
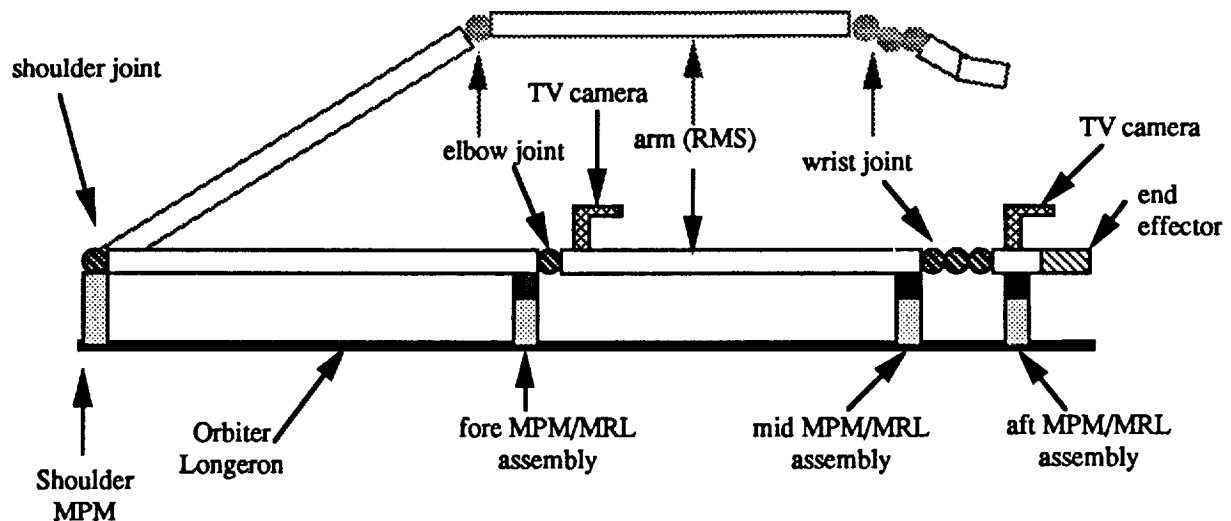


Payload Deployment and Retrieval System
Operator Function Model
Level: 0.0

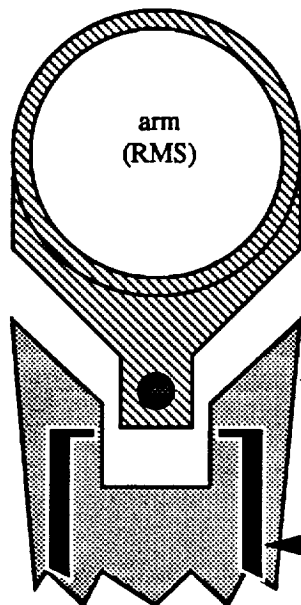


Payload Deployment and Retrieval System
Operator Function Model
Level: 2.0

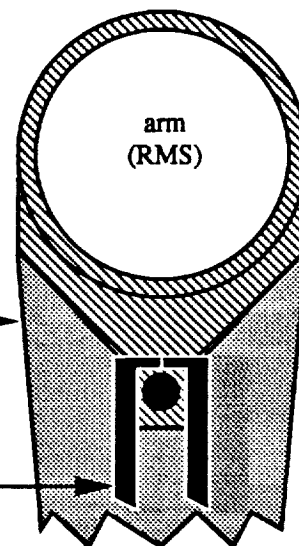




Ready to Latch Position

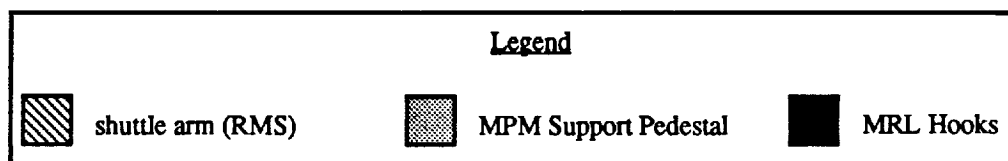


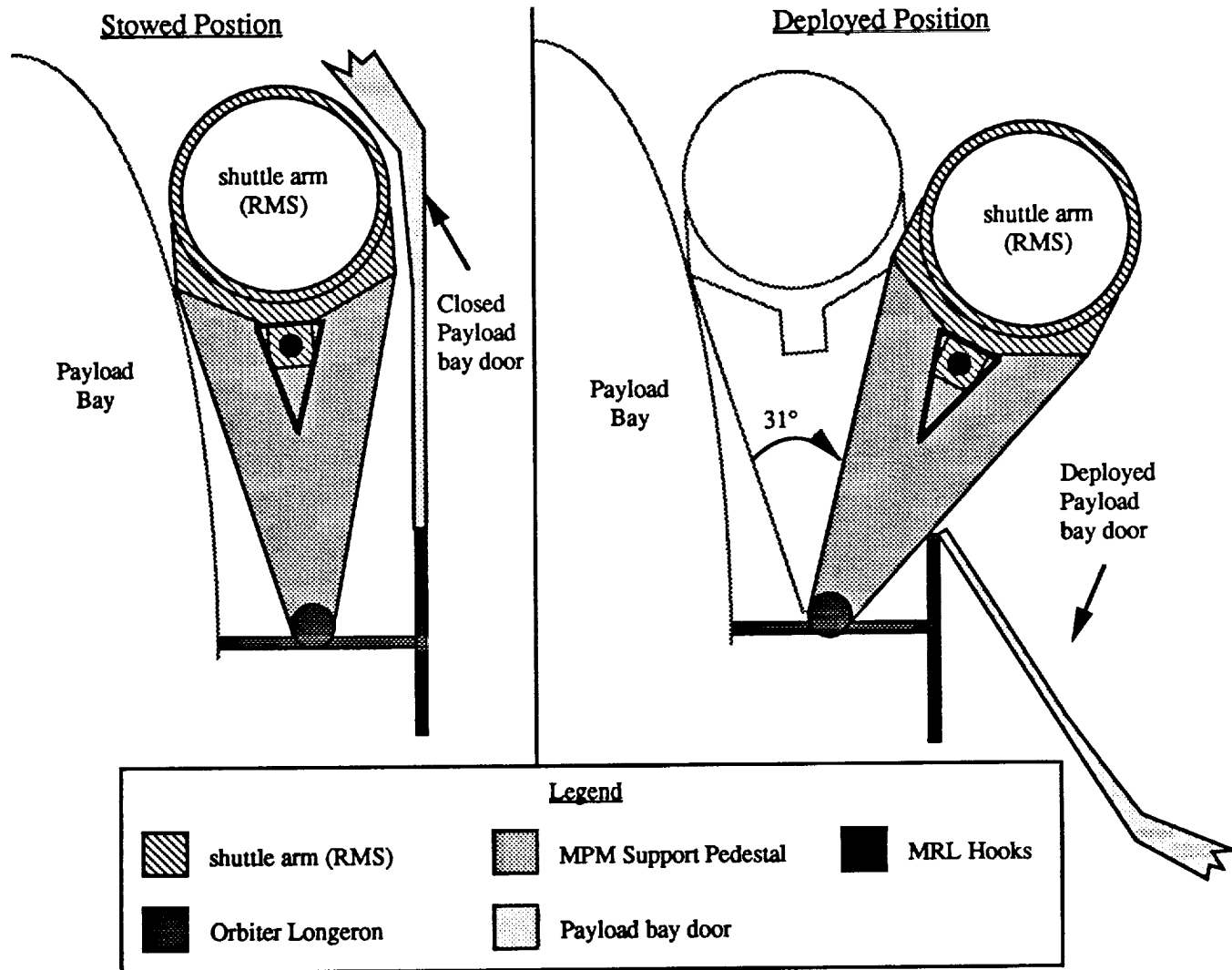
Latched Position

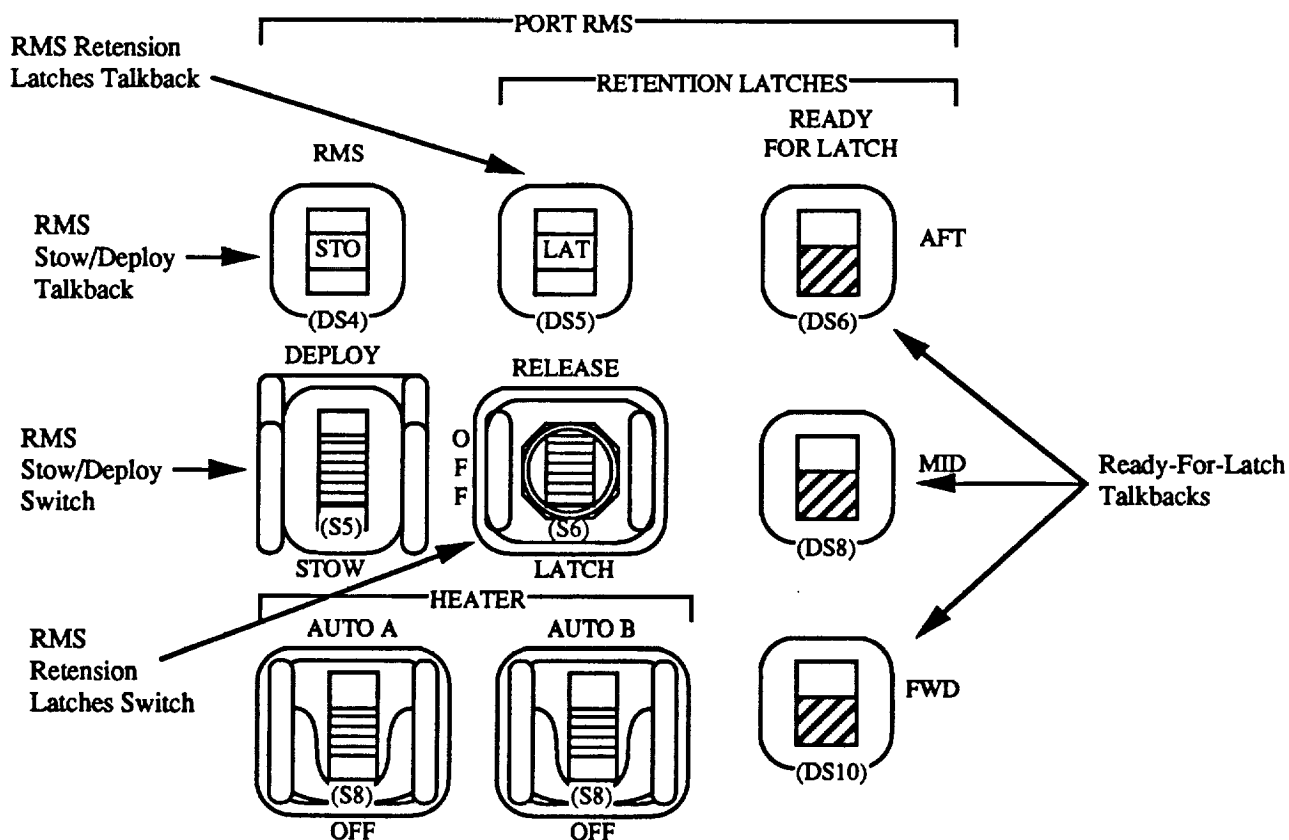
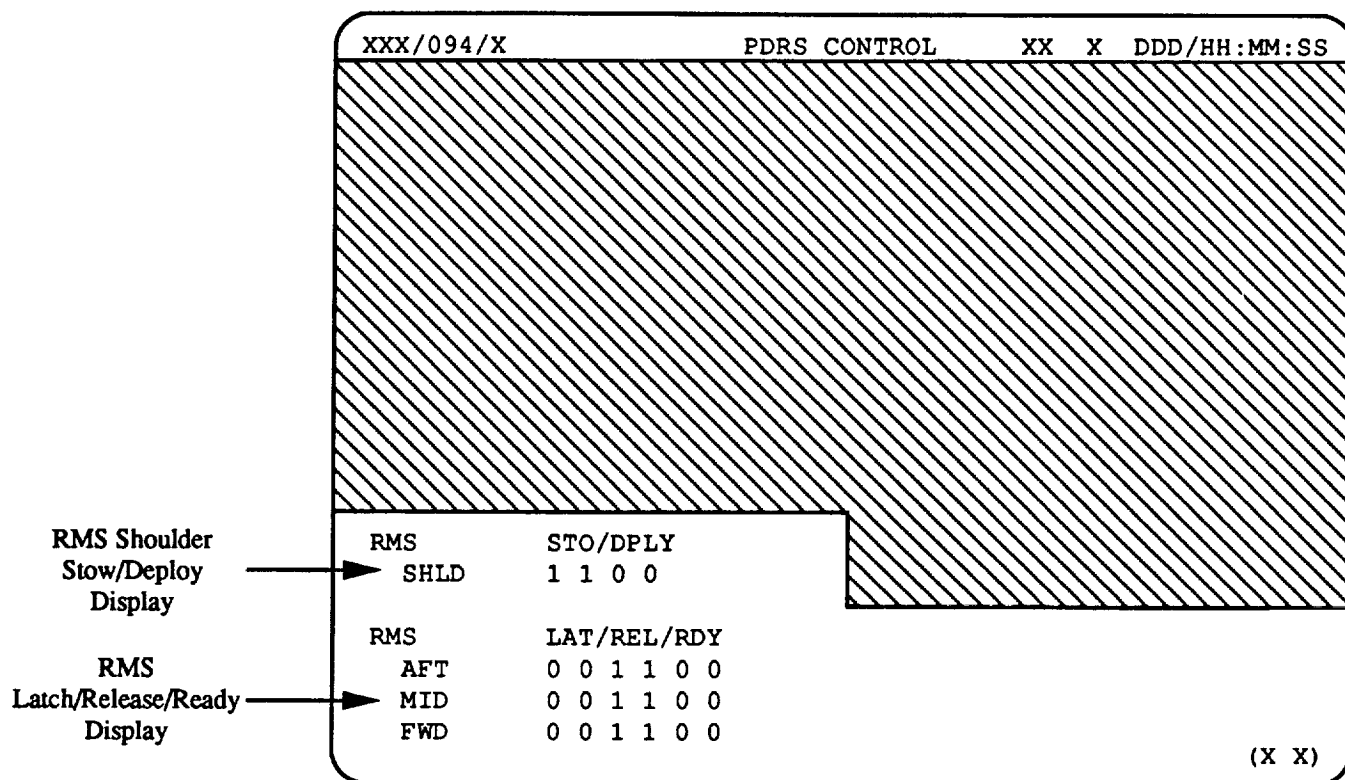


Manipulator
Positioning
Mechanism
(MPM) Support
Pedestal

Manipulator
Retention
Latch (MRL)
Hooks







Appendix C

Mitchell, C. M. (1993) Cognitive Engineering Models: A Prerequisite to the Design of Human-Computer Interaction in Complex Dynamic Systems. in P. Polson (ed.) *Human Computer Interface Design: Success Cases, Emerging Methods, and Real-World Context*. New York: Morgan Kaufman.